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ABSTRACT

R410a Refrigerant which is one of HFC refrigerants is being considered to be a promising replacement for R22 which is widely used in air conditioners. The rotary compressor for R410a has lower energy efficiency than that for R22 because of the high pressure difference between suction chamber and discharge chamber in the compression part. Also the re-expansion gas loss of the rotary compressor for R410a which occurs at a discharge port becomes larger than that for R22 due to high density of R410a refrigerant. Therefore for the purpose of high energy efficiency, we have carried out P-V analyses for various design parameters of the discharge system. The results such as performance data, over-compression losses, and re-expansion losses are acquired by P-V (Pressure-Volume) analyses and analyzed specifically for various parameters. As a conclusion, we could find out the effects of several designs parameters of its discharge system and reduce its losses of re-expansion and over-compression.

INTRODUCTION

The research on the discharge system of the rotary compressor for R22 has been carried out for several years to increase the energy efficiency because it has great influence on the performance [1] [2] [3]. Nowadays there is a great trend in the world wide air conditioner industry that R22 refrigerant has been changed to R410a which is one of promising alternative refrigerants for our ozone conservation. It is necessary that the discharge system of the rotary compressor for R410a should be redesigned to improve its discharge loss because it has larger re-expansion loss than that for R22 [4]. However it is very difficult that the optimal dimensions of the discharge system are found out because there is a trade-off relation between the losses of re-expansion and over-compression generally. Therefore we carried out loss analyses for various design parameters of the discharge system by using our P-V analysis technique and analyzed their effects on the compressor performance.

P-V analysis method

The characteristics of R410a refrigerant

As you can see Table 1,R410a refrigerant has higher pressure, pressure difference, and density than R22. On the basis of same displacement the compressor for R410a has larger cooling capacity but lower EER than that for R22 due to higher its density and pressure difference respectively. Also the above characteristics have a great influence on the design of the discharge system of rotary compressor for R410a.

The simulation program for discharge system design

The structure of our simulation program for predicting performance on a discharge system of a rotary compressor, which has been used to decide its basic dimension, is as follows.

1 1)Model on valve dynamics (effective flow area and force area)

2)Model on pressure pulsation in cylinder and muffler

2 3)Model on leakage and re-expansion process in cylinder

The experimental apparatus for P-V analysis

The apparatus for P-V experiment that is depicted in Fig.1 has a lot of merits such as convenient measurements, a little modification to actual compressors, and a little effort. The positions of pressure sensors and a gap sensor for measurements of pressures and a reference angle respectively are shown in Fig.2. For the purpose of P-V analyses we need to measure relative pressures in suction and compression chambers which are converted to absolute pressures by reference to an absolute pressure in a suction pipe at a reference angle (zero rotational angle). The signals measured are processed and analyzed by a P-V analysis program.

The definitions of efficiencies and losses

Indicated losses on a P-V diagram are illustrated in Fig.3 and several efficiencies are defined in Fig.4. The discharge system is closely related to its losses of over-compression and re-expansion on the P-V diagram and has a great influence on indicated and volumetric efficiencies. The over-compression loss results from the pressure difference between cylinder and muffler pressures to open a valve and keep it opened during discharge process. And the re-expansion loss is caused by re-expansion of residual gas in discharge port after discharge process. Also re-expansion gas makes a lot of volumetric loss. Therefore it is very important that the above discharge loses are reduced by optimal design to improve performance of compressors.

The structure of a discharge system

The discharge system of a rotary compressor as shown in Fig.1 is consisted of a cutout passage on a cylinder, a bore passage in main bearing, a flat type valve seat, a discharge valve, a retainer. The compressed vapor refrigerant in compression chamber flows through a cutout passage, a bore passage, and is discharged to a muffler chamber through effective flow area of a valve. The major parameters of this study are valve thickness, valve lift which is height from a valve seat to a retainer at an outer part of a valve seat, and effective valve length from a bore center to an end part of a main bearing slot.

RESULTS

The effect of valve thickness

The effect of valve thickness on performance is shown in Table 1. There are little difference in the capacity and input between 0.83t and 1t. But the comparison of 1t to 1.25t represents somewhat down in EER in the case of 1.25t because the input is increased. And the above reason is that over compression loss of 1.25t is increased by 17% . Therefore we can understand from Fig.6 that over stiffness occurs larger over compression loss than normal stiffness due to sudden down motion of valve for discharge process.

The effect of valve lift

Even though valve lift has big effect on performance usually it has little effect on over compression loss in the range from1H to 2H as shown in Fig.7. Thus we can conclude that the amount of lift beyond minimum value has no effect on over compression loss though an extremely low value of lift degrades the performance of a compressor due to increase in over compression loss.

The effect of effective valve length

The effect of effective valve length is represented in Table 1 and Fig.8. The comparison of 1L to 1.24L of effective length show us a little increase in EER because of increase in capacity and decrease in input. The longer length improves the over compression loss by decreasing discharge pressure over a wide range for the discharge process. This phenomenon may result from eager open and stronger open state due to longer arm of moment in the case of longer length 1.24L.

The effect of tool angle

We can see the effect of tool angle (or cutout angle) from Fig. 9 . The larger angle has somewhat lower cooling capacity and a little lower input power than the smaller angle. The above reasons are that the volumetric efficiency is somewhat low due to large dead volume and the indicated efficiency is a little high due to somewhat low over compression loss shown in Fig.9 in the case of the larger angle respectively. As you can see in Fig.9, over compression loss is a little low because of delayed discharge angle while there is little improvement in over compression loss for the discharge process. Also there are a little increase in re-expansion loss due to large dead volume in the case of the larger angle. It is clear that the larger angle has lower EER because the volumetric efficiency is somewhat lower due to large dead volume while the indicated efficiency is a little higher due to low over compression loss. Therefore it is known that the tool angle is very sensitive to performance and should be selected optimally to increase EER.

CONCLUSIONS

The conclusions resulted from actual compressor tests for various parameters are as follows.

- ◆ There is a second over compression phenomenon for the discharge process in the case of over valve thickness. And it increases over compression loss for the discharge process. Then there is difference in EER by 0.8% between normal thickness and over thickness.
- ◆ It is clear that the effect of valve lift on performance is very tiny in the range of lift values tested.
- ◆ The long effective length of valve has a little lower over compression loss for the discharge process than the short that. The reason is that it makes the valve opened for the discharge process. Then there is a difference in EER by 0.7% between long length and short length.
- ◆ The small tool angle has somewhat higher volumetric efficiency due to small dead volume and higher over compression loss due to advanced discharge angle than the large tool angle. It reveals that the trade- off relation exists between over compression loss and re-expansion loss from our test result. Thus we should select the optimal tool angle by considering above relation. Also there is a big difference in EER by 1.4% between small tool angle and large tool angle.
- ◆ As a final conclusion we could develop a higher efficiency rotary compressor for R410a by about 3% in EER by optimizing various parameters on a discharge system base on our actual test results than a previous one.

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Table 1. R410a Characteristics [ASHRAE-T]

Item	R22	R410A	R410a/R22
Suction Pressure(Kgf/㎠.A)	6.37	10.15	
Discharge Press.(Kgf/㎠.A)	21.87	34.17	
Suction Temperature (℃)	35	35.1	
Liquid Temperature (℃)	46.1	46.0	
Δ EVA Enthalpy (Kcal/kg)	40.51	42.97	1.06
Δ COMP.Enthalpy (Kcal/kg)	8.43	9.628	1.14
Suction Gas Density(Kg/m³)	23.19	31.69	1.37
Δ Pressure (Kgf/㎠.A)	15.5	24.02	1.55
Cooling Capacity (Btu/h)	15,123	21,922	1.45
Theoretical Max. EER	16.4	15.23	0.93

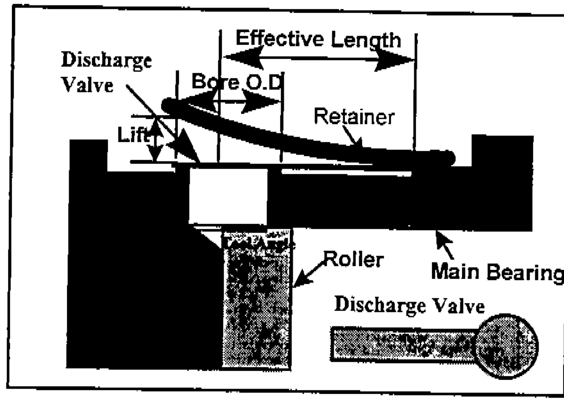

Fig. 1 A discharge system structure

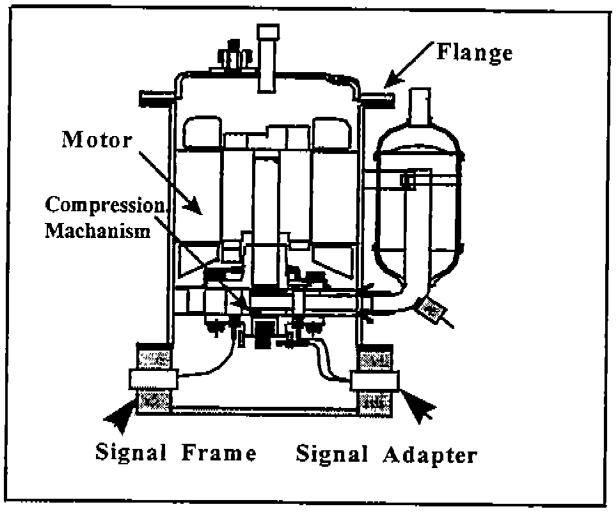

Fig. 2 A experimental apparatus

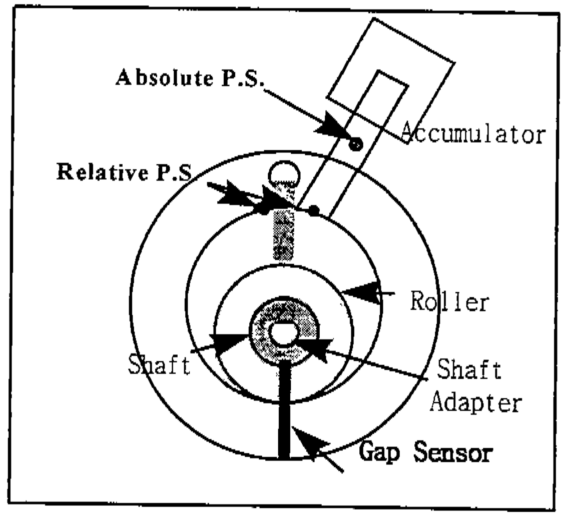

Fig.3 Positions of pressure and gap sensors

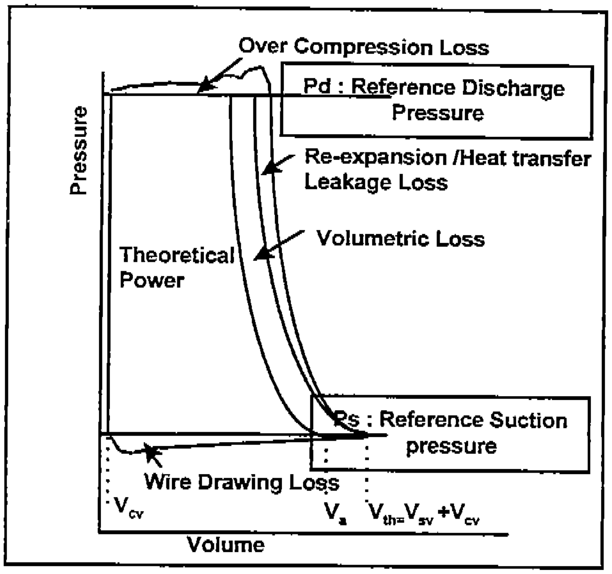

Fig. 4 An illustrative P-V diagram

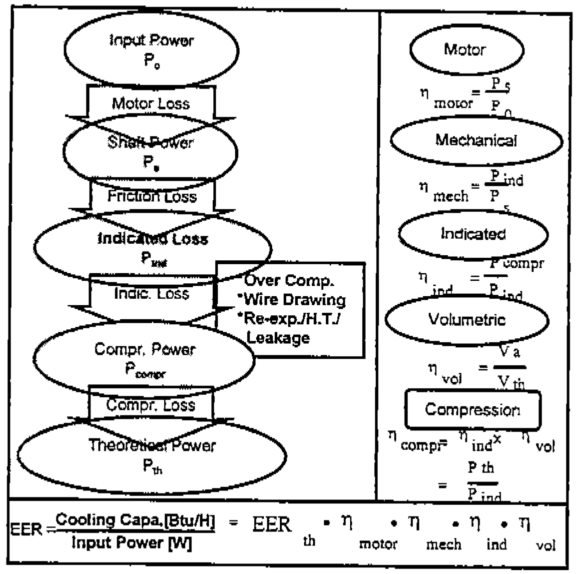

Fig.5 Definitions of losses and efficiencies

Table 2. The efficiencies and losses according to design parameters of a discharge system

	Item	Unit	Valve Thickness (t)			Valve Lift (H)			Effective Length (L)		Tool Angle (Θ)	
			A:0.83	B: 1	C: 1.25	D: 1	E: 1.5	F: 2	G: 1	H: 1.24	I: 1	J: 1.65
PER	Capacity	%	100.12	100.00	99.92	100.00	100.09	100.03	100.00	100.47	100.00	97.99
	Input	%	99.85	100.00	100.43	100.00	99.78	99.85	100.00	99.78	100.00	99.42
	EER	%	100.31	100.00	99.48	100.00	100.21	100.10	100.00	100.72	100.00	98.56
EFF	Indicated	%	100	100.00	98.98	100.00	99.54	99.77	100.00	99.77	100.00	101.37
	Volumetric	%	100	100.00	99.89	100.00	100.22	100.11	100.00	100.45	100.00	97.89
LOSS	Over Compression	%	92.86	100.00	116.67	100.00	104.76	102.38	100.00	88.64	100.00	92.31
	Re-Ex/L/H.T.	%	101.19	100.00	101.19	100.00	101.80	101.80	100.00	101.18	100.00	101.75
SPEC	Thickness (t)	%	83	100	125	100	←	←	←	←	←	←
	Lift (H)	%	100	←	←	100	150	200	100	←	←	←
	Effective Length(L)	%	100	←	←	←	←	←	←	124	←	←
	Tool Angle (Θ)	%	100	←	←	←	←	←	←	←	←	165

The Same Bore Diameter

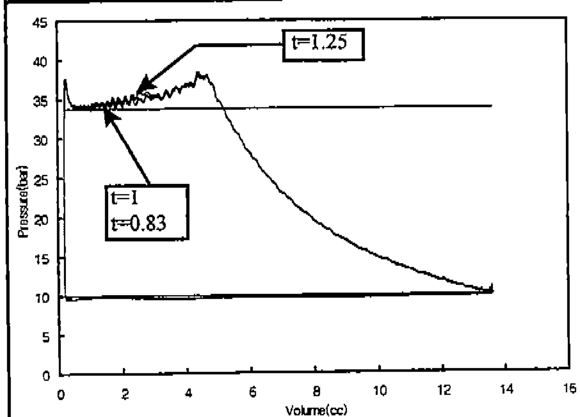

Fig.6 The P-V diagrams according to valve thickness

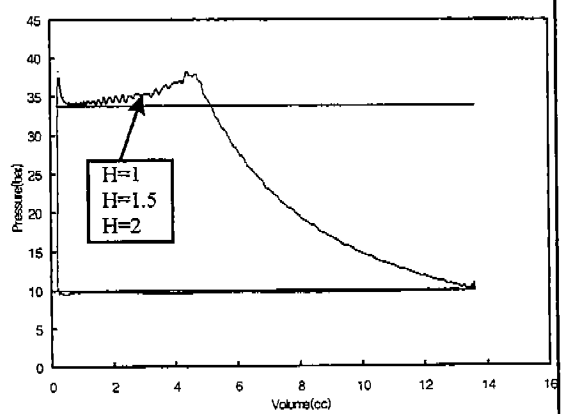

Fig.7 The P-V diagrams according to valve lift

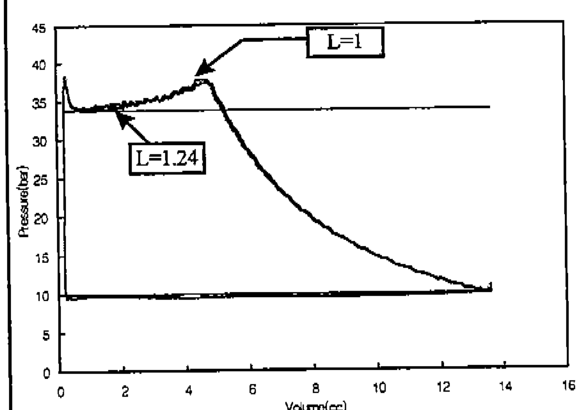

Fig.8 The P-V diagrams according to valve effective length

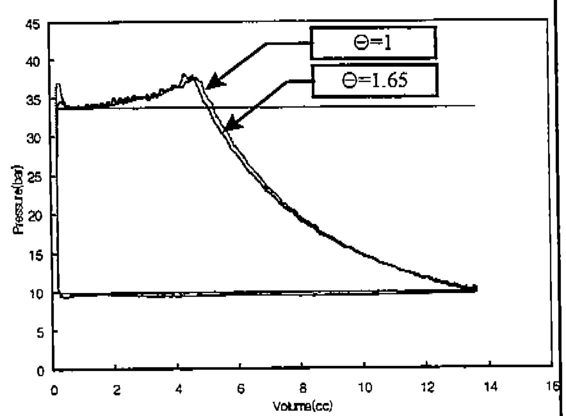

Fig.9 The P-V diagrams according to tool angle